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HONEYBEES' BEHAVIOUR IN A FARADAY-SHIELDED HIVE: MANDATORY SCHUMANN RESONANCE FOR COLONY SURVIVAL

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ABSTRACT

Research shows that low-level anthropogenic electromagnetic fields negatively impact various species in their behaviour, affecting orientation, migration, foraging, reproduction, nesting, territorial defense, vitality, and survival. Many insects, like honeybees, rely on Earth's electromagnetic fields for orientation and foraging. The honeybees react negatively to anthropogenic multi-frequency interference through multi-sensory mechanisms. In order to circumvent the potentially negative effects of external electromagnetic influence, the honeybees were kept in Faraday hives. Placing honeybees in such Faraday-shielded cages, which block external electromagnetic fields, effectively isolates them from natural electromagnetic frequencies. However, the long-term survival of the honeybees in such Faraday hives was only possible with the artificial re-introduction of the Earth's natural electromagnetic environment, the Schumann resonance. Honeybees placed in Faraday cages without access to the Schumann resonance experience a range of effects, including physiological impairments to the queen of the honeybees' colony, which stops laying fertilized eggs. This is leading to the collapse of the colony, which is finally containing only immature female workers and drones. These findings highlight the significance of natural electromagnetic fields in maintaining homeostasis and normal biological functions of honeybees. Further research is needed to explore factors like electromagnetic radiation affecting honeybee physiology and behaviour. The combined effect of multiple stressors, interacting across space and time, likely plays a central role in the global decline of honeybee health.

Keywords: Honeybees, RF-EMF, Anthropogenic Electrosmog, Faraday Hive, Shielding, Earth' Schumann Resonance

1. INTRODUCTION

Honeybees face global threats, with colony collapse disorder (CCD) linked to factors such as varroa mites, pesticides, immune stress, drought, monoculture, migratory stress, and pathogen transmission Brown et al. (2016), Decourtye et al. (2019). The CCD is a recent phenomenon Vanengelsdorp (2009).

Nonionizing electromagnetic fields (EMFs, 0–300 GigaHertz, GHz) span frequencies between visible light and Earth's natural static fields. They are widely used in modern technologies, including power distribution, wireless communications (WiFi, cell phones, 2–5G), smart devices, broadcasting, radar, satellites and military applications International Commission on Non-Ionizing Radiation Protection ICNIRP (2020). Studies show that low-level anthropogenic EMFs negatively affect various species, disrupting orientation, migration, foraging, reproduction, nesting, territorial behavior, and overall survival. Increasing exposure to electromagnetic radiation from mobile phones and antennas is likely contributing to the disturbance or the decline in insect populations, as suggested by various studies Genersch (2010), Halabi et al. (2013), Levitt et al. (2022), Migdał et al. (2022), Panagopoulos (2013), Vanbergen et al. (2019), Watson and Stallins (2016). It was shown that mobile phones and the ambiant electromagnetic pollution is inducing the worker piping signal in stressed honebees' colonies Favre (2011), Favre (2017). Honeybees can be disturbed during peculiar events, such as during the New Year's Eve Favre and Johansson (2020). Additionally, EMF exposure exerted strong physiological stress on honeybees, affecting gene expression related to stress and behavior, and leading to decreased pollination efficiency Molina et al. (2023).

In 1836, Michael Faraday (1791-1867), the English scientist who specialized in electromagnetism and electrochemistry, first constructed the so-called Faraday cage or Faraday shield Faraday (1832). A Faraday shield is a conductive enclosure that blocks electromagnetic fields by redistributing electric charges. It is used for shielding various objects (electronics, etc.) from interference, securing data, protecting against lightning, enabling scientific experiments, preventing medical device disruptions, and safeguarding electronics from electromagnetic pulses (EMP) damage Celozzi et al. (2023).

Experiments placing various animal species in Faraday shields include rodents and birds. Mice placed in Faraday cages showed increased levels of cortisol (a stress hormone) and exhibited disturbed sleep patterns and reduced ability to cope with stressors Febinger et al. (2014). Studies on migratory birds indicated that artificial EMF shielding affected their ability to orient and navigate, even when geomagnetic fields were not blocked Morrison (2014). These studies suggest that both the presence and the absence of EMFs can influence various biological processes across different species. Scientific research specifically examining the effects of placing insects, and especially honeybees, in a Faraday shield to isolate them from external electromagnetic fields is very scarce. Therefore, in order to assess whether such an environment can have various physiological and behavioral effects on honeybees, experiments were performed by maintaining honeybees' colonies in hives that were especially constructed for this purpose. To our knowledge, this is the first time that honeybees are evolving in the long-term in such a peculiar environment.

2. MATERIALS AND METHODS

2.1. CONSTRUCTION OF A FARADAY-SHIELDED HIVE

The plans for a standard Dadant-Blatt beehive with 12 frames were considered for the construction of a Faraday hive protected with an aluminium shield. The details for the construction of the Faraday-shielded hive are beyond the scope of this article and will be detailed elsewhere (Daniel Favre and Bernard Anker, manuscript in preparation). Basically, the inside of the brood box is measuring 470 x 435 x 300 (height) mm. In the main body's core, the aluminium sheet having round holes (Alfer™ GMbH, combitech® system Sheet, https://products.alfer.com; thickness 0.7 mm) is sandwiched between two massive larch wood, each one-centimeter thick. The floor board of the hive is also made of aluminium with round holes. The roof is constructed with aluminium with round holes, and is having aluminium profiles allowing efficient joint closure Figure 1.

In order to appropriately shield against 900 MHz electromagnetic waves while keeping a 30 cm × 2 cm opening in the front side of the hive, we need to use metal rods with appropriate spacing to block the incoming radiation Celozzi et al. (2023), Ohmura et al. (2014). The wavelength of a 900 MHz radiation is about 33.3 cm. To effectively block 900 MHz radiation, the spacing between the rods should be significantly smaller than the wavelength. A common guideline is to use a spacing of less than 1/4 of the wavelength. The rods should be placed vertically across the 30 cm opening to block horizontally polarized waves. A spacing of 1/4th of the wavelength is thus 8.33 cm. Since 6 cm is smaller than 8.33 cm, it is below the 1/4 wavelength limit, meaning it should still provide reasonable shielding.

Figure 1

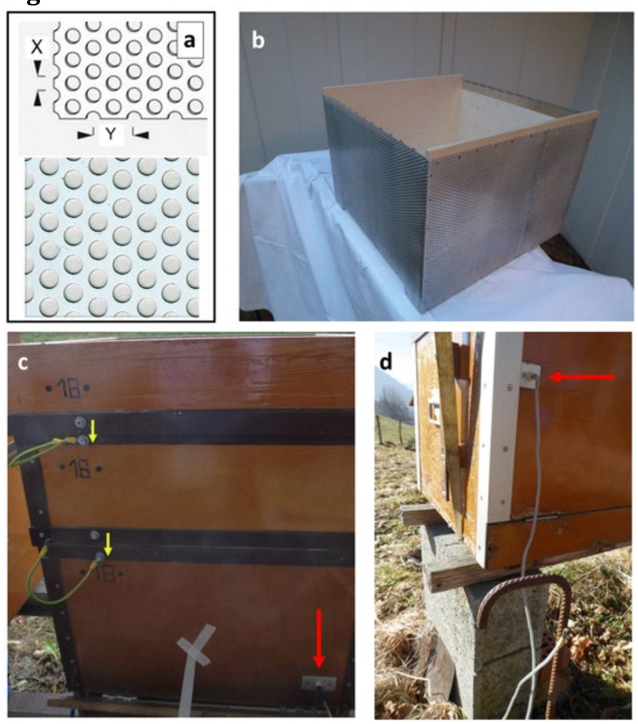

Figure 1 Construction of Faraday-shielded hives and connection to the ground. a : Aluminium sheet with round holes. X = 1.6 mm. Y = 3.0 mm. b : Aluminium core during the construction. c, d : grounding of the hives to the ground allowing the Foucault's (eddy) electric currents to leak into the ground. Yellow arrows are showing the connection between the roof, the super and the main body of the hive. Here, the hive is ready for a visit performed by the beekeeper. Red arrows are showing the connection of the hive to the 10 mm-in-diameter metallic rod employed for grounding

2.2. SPECIFICATIONS OF THE FARADAY-SHIELDED HIVE

For the specifications of a Faraday-shielded hive, the attenuation factor has to be measured, since it quantifies how effectively the cage shields its interior from external electromagnetic fields. It is typically expressed in decibels (dB). It is defined as:

$$A = 20 \log_{10} \left(\frac{E_{\text{outside}}}{E_{\text{inside}}} \right)$$

where A is the attenuation factor in dB, $E_{outside}$ is the external electric field strength in Volts per meter (V/m), and E_{inside} is the internal electric field strength. The electromagnetic field strength outside the Faraday cage will generally be weaker to begin with, especially if the source is distant. The distance from the source itself causes the intensity of the electromagnetic waves to naturally attenuate by the inverse square law, which means the further away the hive is from the source, the less intense the field becomes. The spacing of rods in a Faraday cage is related to waveguide cutoff frequency and aperture shielding, both of which are covered in microwave engineering books Morrison (2016), Ramo et al. (1994).

An anechoic chamber is a specially designed room that minimizes sound reflections and external noise to create an environment that is as close to completely silent as possible. The term "anechoic" means "without echoes." These chambers are used for various acoustic and electromagnetic tests. Therefore, the Faraday-shielded hive was tested in the anechoich chamber of the School of Engineering at the Swiss Federal Institute of Technology (EPFL, room ELL 937.0) in order to obtain the characterisation of the attenuation factors at 900 Megahertz (MHz). For this, according to the cognate experimental setup, the following apparatuses were employed in the anechoic chamber of the EPFL : signal generator IFR type 2023A; high frequency (HF) amplifyer Prâna MT21; log-periodical antenna Schwarzbeck UHALP 9107, isotropic field probe Amplifier Research FM2000/FP 2000. The height of the antenna and the probe was H=117 cm above the ground level. The distance between the antenna and the probe was D=3m Figure 2.

Figure 2

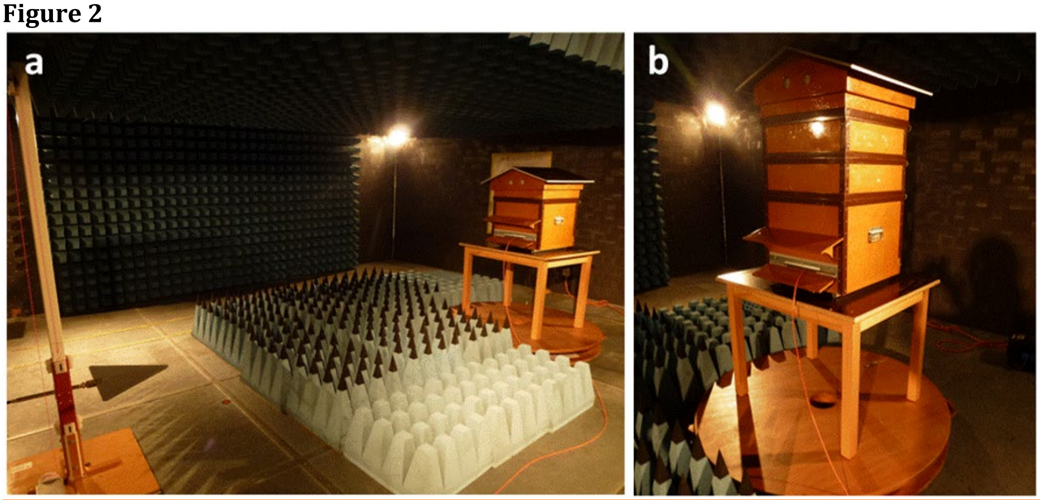

Figure 2 Faraday-shielded hive in the anechoic chamber. a : Faraday-shielded hive without "supers"(employed for honey storage). b : Faraday-shielded hive with two "supers". The probe is placed within the hive.

For the consideration of the fundamental electric field strenth of the Schumann resonance Nickolaenko and Hayakawa (2014), Schumann (1952), Sentman (2017), the value of 0.02 V/m was considered. Indeed, the Schumann resonance frequencies are typically around 7.83 Hz, and they are associated with very low-frequency (VLF) electromagnetic waves. The magnetic field strength of Schumann resonance modes is often quoted as being in the range of 50 nT to 100 nT (nanotesla). Using the relationship E = c × B (where E is the electric field in V/m, B is the magnetic field in Tesla, and c is the speed of light), the corresponding electric field strength of the Earth Schumann resonance is, with a conventional 50 nT magnetic field, of around =0.015 V/m.

The electric field E_{inside} a Faraday cage is given with a similar formula, where $E_{outside}$ is the electric field strength of the Schumann resonance, having :

$$E_{\text{inside}} = E_{\text{outside}} \times 10^{-\frac{\text{Attenuation (dB)}}{20}}$$

2.3. HONEYBEES' COLONIES

The study of honeybee colonies kept in two Faraday hives took place in a rural area of Switzerland, close to the city of Montreux and at an altitude of 960 m above sea level, as described elsewhere Favre and Johansson (2020). There is only one local emitting antenna in direct view (CH1093+/ LV95, https://www.bakom.admin.ch/bakom/en/homepage/frequencies-and-antennas/location-of-radio-transmitters.html), located about 950 m away from the hive. The intensities of the ambient RF-EMF ranged from 0.05 to 0.2 μW/m^2, as regularly measured with the use of the high frequency analyser HF59B (Gigahertz Solutions). During the autumns and winters, the bees had been treated against the varroa mite *Varroa destructor* with formic acid and oxalic acid, as recommended elsewhere (Agroscope Liebefeld-Posieux, Swiss Bee Research Center; Charrière et al. (2004). The experiments with honebees that were kept in Faraday-shielded hives started in early spring 2013 and lasted until mid-2024.

2.4. ANALYSIS OF THE SCHUMANN GENERATOR

The Schumann generator (model CF-FM783-BA from the manufacturer Shairann, China) that was employed throughout these experiments has a size (7 x 5.5 x 1 cm) that is well suited for an easy introduction in the hive from it's front entrance. According to the manufacturer specifications, the charging current of the Schumann generator is 250 mA, the product can be fully charged in about 6 hours, and the working current is approximately 7 mA, so that it can be used for about 200 hours when fully charged. The Schumann wave that is emitted is, according to the manufacturer, 7.83 Hz. Since it was absolutely crucial to confirm that the emitted electromagnetic wave was indeed at 7.83 Hz, the Schumann generator was analyzed using an ELF-receptor specifically designed for the analysis of the extremely low frequencies (ELF) of the electromagnetic waves. For this purpose, the ELF-receptor was placed close to the Schumann generator that was employed for the emission of the electromagnetic signals. The ELF-receptor was connected to a vocal recorder (Olympus LS-11) linked to an external battery (Panasonic LC-R123R4P; https://na.industrial.panasonic.com/) via a 12V-to-3V voltage converter (Dupertuis Electronique S.A., Lausanne, Switzerland) Figure 3. The recorded signal was digitized as a waveform audio/sound file with 44.1 kHz recording mode. The open source, cross platform audio software Audacity (https://www.audacityteam.org/), was employed for the manual analysis of the signal and for the generation of the audiograms (also called sonograms).

Figure 3

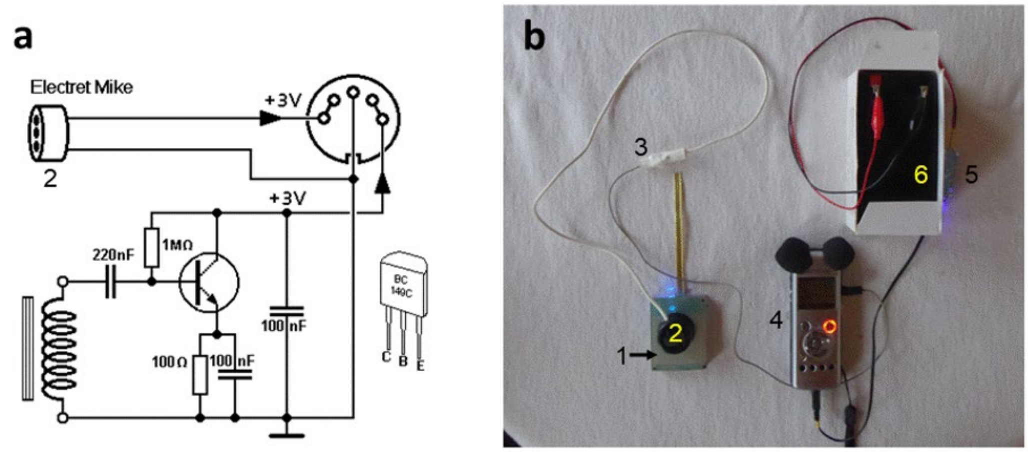

Figure 3 Devices and setup for the analysis of the electromagnetic waves emitted by the Schumann generator. a: electronic circuit. "Electret Mike" refers to "electret microphone". b: experimental setup. 1: Schumann generator. 2: Electret microphone. 3: Electronic components. 4: Olympus LS-10 recorder. 5: 12V-to-3V voltage converter. 6: Battery. In the real experimental setup, all the components in b were placed apart from each other, and the recordings were performed away from ambient electric wires.

3. RESULTS

3.1. FARADAY-SHIELDED HIVE IN THE ANECHOIC CHAMBER

The analyses in the anechoic chamber at the Swiss Federal Institute of Technology revealed that the attenuation factors of the Faraday-shielded hive were comprised between 8.6 and 28.8 dB, depending on the side of the hive that was taken into consideration Table 1.

Table 1

Table 1 The Measured Electromagnetic Field at 900 MHz in the Vicinity of the Probe and without the Presence of the hive was Eo = 22 V/m

Configuration	Position	Field (V/m)	**Attenuation factor [dB]**
	Front side	0.8	**28.8**
Simple hive	Back side	1.95	**21**
	Left side from inside	8.2	**8.6**
	Right side from inside	4.6	**13.6**
	Front side	2.02	**20.7**
Hive with two supers	Back side	1.62	**22.7**
	Left side from inside	5.8	**11.6**
	Right side from inside	3.55	**15.8**

The ambient Schumann resonance field (natural Earth's field) is, as mentioned previously, about 0.015 V/m (15 mV/m). The electric field strengths inside the Faraday-shielded hive (after attenuation) are given in the Table 2.

Table 2

Table 2 Electric Fields Inside the Faraday-Shielded Hive and Percentage of Reduction of the Corresponding Electric Fields when Compared to the External Schumann Resonance Field Strength. Values are given in Decibels [dB] and Millivolts Per Meter [mV/m].

Attenuation factors	8.6 [dB]	28.8 [dB]
	(worst case)	(best case)
Electric field inside	5.6 [mV/m]	0.531 [mV/m]
E_{inside}		
Percentage of reduction in the electric field	≈ 62.7 %	≈ 96.5 %

3.2. COLLAPSE OF HONEBEES' COLONIES IN THE ABSENCE OF A SCHUMANN GENERATOR

During the first years (2013-2022) spent for the investigation of the fate of honeybees' colonies in Faraday-shielded hives, the colonies behave disoriented since the queen was not anymore able in laying eggs giving female worker bees, especially after winter. Worker bees could not raise new queens with young eggs, feeding them with royal jelly: newly-built queen cells were not observed anymore. After winter, it was observed that there were no new worker bees emerging from the hexagonal cells in the hive. More and more drones (males) were emerging from the hexagonal cells. This revealed that some worker bees begun laying unfertilize eggs. The result was an overall population decline.

In order to circumvent the observed population decline, the introduction of a mated queen from reputable suppliers was performed. Unfortunately, this did not help in maintaining viable honeybees' colonies. Introducing queen cells or virgin queens from another hive did not help, neither. The colonies were always kept with sufficient food, space, and protection from pests and diseases in order to ensure resilience and for allowing their ability to raise a new queen. Unfortunately, all these conditions and procedures were also unsuccessful.

The long-term colony survival, stability, and productivity was never obtained in a Faraday-shielded hive.

It finally turned out that the presence of a Schumann generator was absolutely crucial for the well-being of the honeybees' colonies in the long-term. Two honeybees' colonies from "regular" hives were transferred into the Faraday-shielded hives in the mid-April 2022, and the Schumann generators were placed simultaneously in these Faraday-shielded hives. This allowed the survival of the colonies until mid-June 2024, after which time the honeybees were put again in "regular" hives, since the maintainance of such a Schumann generators is requiring constant control and does not allow vacations longer than a week (not said that it is also time consuming).

3.3. ELECTROMAGNETIC FIELDS EMITTED BY THE SCHUMANN GENERATOR

The Schumann generator that was employed in this study is emitting electromagnetic pulses every 128 milliseconds (ms). This signal is thus emitting with a frequency of 7.8125 Hz, close to 7.83 Hz. Therefore, the Schumann generator could be placed with confidence in the two Faraday- shielded hives that were employed in this study Figure 4. Experiments with the presence of a Schumann generator in the two Faraday- shielded hives started in early spring 2022.

Figure 4

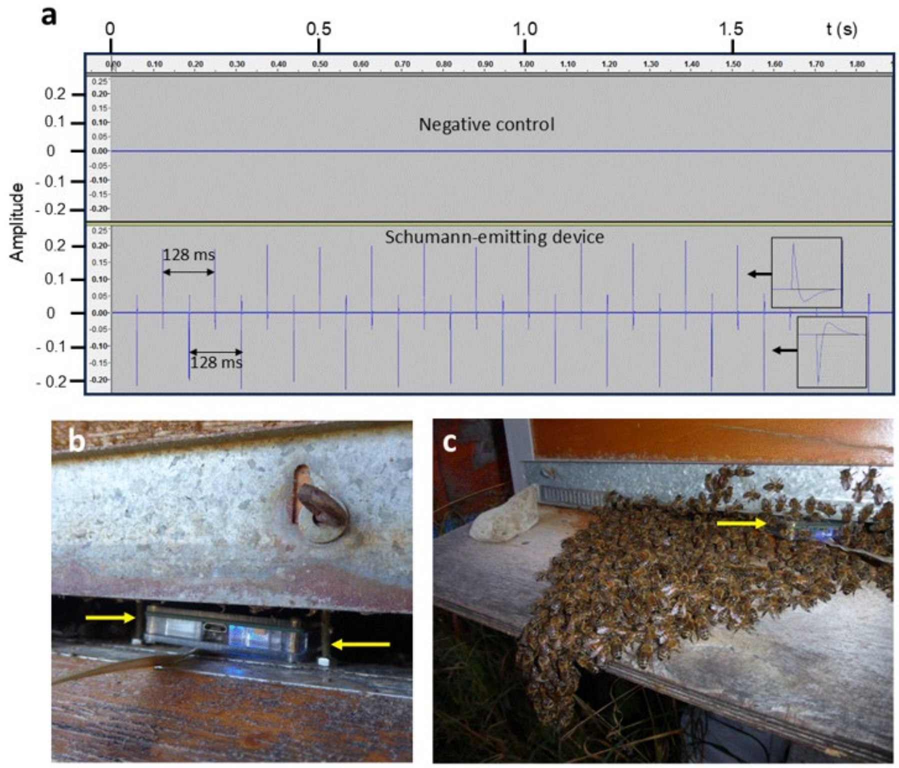

Figure 4 Characterization and use of the Schumann generator. a : Audiogram of the EMFs emitted by the Schumann generator. Audiogram is normalized (-0.2 to 0.2). The negative control was performed using the Schumann generator in the OFF setting (upper panel), whereas the lower panel is showing the sonogram with the ON setting (lower panel). Time (t) is in seconds (s). Enlargement of the waves in panels, on the right hand side. b : Schumann generator in the entrance of the Faraday-shielded hive. Note that the entrance is made of vertical metallic rods (arrows) that are 6 cm apart from each other. c : careful introduction of the Schumann generator (arrow) in a very populous honeybees'colony

4. DISCUSSION

4.1. MAGNETORECEPTION OF HONEYBEES

The honeybee (*A. mellifera*) was one of the first animal species for which the existence of a magnetic sense has been proposed Lindauer and Martin (1968). Pioneering research demonstrated that honeybees can detect geomagnetic fields, using magnetite particles in their bodies as part of their sensory system Hsu (2007), Kirschvink (1981) Lambinet, et al. (2017), Lambinet, et al. (2017). It has been proposed that honeybees' magnetoreception is tied to cryptochrome proteins, which are sensitive to magnetic fields and could be affected by shielding or EMF exposure Fleischmann et al. (2020). The key concern is whether radio frequency (RF) electrosmog from modern civilization disrupts honeybee compass abilities and affects their fitness Válková and Vácha (2012). Two main hypotheses explain how Hymenoptera detect the geomagnetic field (GMF): the ferromagnetic hypothesis Shaw et al. (2018) and the biochemical hypothesis Hore and Mouritsen (2016).

4.2. THE SCHUMANN RESONANCE

The Schumann resonance is a natural electromagnetic phenomenon in the Earth's atmosphere, occurring between the surface and the ionosphere. It consists of standing electromagnetic waves in the extremely low frequency (ELF) range and was mathematically predicted by Winfried Otto Schumann in 1952 Schumann (1952). These resonances are crucial for studying atmospheric physics and Earth's electromagnetic environment, with implications for both the electromagnetic environment and potential biological effects. The Schumann resonance, the Earth's natural electromagnetic field, is oscillating primarily at 7.83 Hz. Additional harmonics occur at higher frequencies, such as 14.3 Hz, 20.8 Hz, and beyond.

The Earth's natural electromagnetic environment, including the Schumann resonance, influences biological processes across species. Pioneer work was performed on humans and green finches Wever (1970). Placing animals in a Faraday cage isolates them from natural electromagnetic fields, including the primary Schumann resonance at around 7.83 Hz. Since animals have evolved with Earth's electromagnetic environment, such isolation can lead to physiological and behavioral effects. While direct studies on insects in Faraday cages are limited, research on other animals suggests that isolation from natural EMFs can cause behavioral and physiological changes. Indeed, natural electromagnetic fields, such as the primary Schumann resonance and its harmonics, appear to function as environmental cues, affecting biological rhythms and development in various organisms Rouleau and Dotta (2014).

4.3. RELEVANCE OF THE EXPERIMENTAL SETUP

With the effective attenuation factor between 8.6 dB and 28.8 dB, the Schumann resonance field inside the Faraday-shielded hive would be substantially reduced. The field strength inside the hive ranged from ~5.6 mV/m (worst case, only on one side) to ~0.531 mV/m (best case) depending on the exact attenuation. The attenuation of the electromagnetic fields is comprized between 62.7% and 96.5%, offering moderate to high shielding effectiveness for the natural Schumann resonance field. Therefore, the experimental setup consisting in aluminum walls and larch wood are providing a significant reduction in the external electromagnetic field, making it a good shield against the Schumann resonance.

4.4. PUTATIVE ROLE OF THE SCHUMANN RESONANCE ON THE QUEEN BEE

The queen bee, as the central reproductive figure of a honeybee colony, might experience effects in a Faraday cage due to the lack of a cognate geomagnetic input. While queen bees do not typically leave the hive to forage or navigate, their behavior and physiological processes could still be influenced by the absence of geomagnetic fields. The potential effects on queen bees might be the following:

1) Honeybees, including the queen, are possessing the sense of magnetoreception, which is an ability to detect Earth's geomagnetic fields. If the queen uses geomagnetic input for orientation within the hive or during the rare instances of swarming, placing her in a Faraday cage might interfere with this natural sense, causing stress or disorientation ;
2) Stress from geomagnetic isolation might affect the queen's production of pheromones, the chemical signals critical for the worker cohesion and hive organization, and for the regulation of worker reproduction and behavior. Any alteration in pheromone levels or composition could destabilize the colony ;

3) The queen's egg-laying behavior might be influenced by stress or disorientation within the Faraday cage. Disruptions could lead to decreased egg-laying rates, and to lower viability of eggs due to stress-induced physiological changes.
4) Scientific research suggests that geomagnetic fields might influence cellular processes in bees, including ion channel activity and metabolic functions. A lack of geomagnetic input could theoretically impact the queen's metabolism, energy levels, or overall health, leading to reduced reproductive efficiency.
5) The absence of geomagnetic fields might also influence worker bees' behavior toward the queen, by reducing the efficiency in feeding and grooming her, or by the potential disruption in the recognition of her pheromones, leading to instability in the hive hierarchy.

Using Faraday cages for controlled experiments on queen bees could provide valuable insights into the role of geomagnetic fields in swarming and mating behavior, the potential stress effects on queen health and pheromone production, and the long-term impacts on hive stability and reproduction.

While the queen bee is less directly reliant on navigation compared to foraging workers, it is hypothésiez that the absence of geomagnetic fields in a Faraday cage could have cascading effects on her health, behavior, and reproductive performance. Indirectly, these effects could destabilize the entire colony, as the queen's well-being is absolutely essential for hive function and survival. For an extensive review on the effects of electromagnetic waves on honeybees, and especially the queen bee, see Levitt et al. (2022).

Further scientific experiments under controlled setups are absolutely required to investigate the queen's physiological and reproductive responses to geomagnetic shielding or disruption. These focused experiments involving queen bees in Faraday cages are an area ready for exploration. The results could deepen our understanding of the broader implications of geomagnetic and electromagnetic disruptions on bee populations and ecosystems.

4.5. PERSPECTIVES

Devices like signal generators or electromagnetic wave oscillators can produce a stable 7.83 Hz electromagnetic field within the Faraday cage. These devices can mimic the natural frequency of the Earth's Schumann resonance, ensuring that animals in the cage experience a similar electromagnetic environment. These devices capable of modulating electromagnetic pulses at frequencies aligned with the Schumann resonance can thus provide a biologically relevant substitute. One should be cautious, since such artificial generators must precisely replicate the Schumann resonance in terms of frequency, intensity, and wave patterns to be effective. Indeed, deviations can lead to suboptimal or unintended effects Patsnap (2024).

While these studies and technologies indicate the possibility of generating Schumann resonance frequencies artificially, implementing such systems within a Faraday cage to study their effects on honeybees would require further careful consideration of several factors, such as signal fidelity (in order to ensure that the generated frequencies accurately match the natural Schumann resonance in terms of frequency, amplitude, and waveform characteristics), environmental control (in order to maintain consistent and uniform electromagnetic exposure within the Faraday cage) and biological monitoring (for the continuous assessment of the physiological and behavioral responses of honeybees to the simulated frequencies). Therefore, artificially recreating the Schumann resonance might need to include harmonics (14.3 Hz (2nd harmonic), 20.8 Hz (3rd harmonic), 27.3 Hz (4th harmonic) and 33.8 Hz (5th harmonic) to fully replicate the natural electromagnetic environment.

5. CONCLUSION

To date, there are very few studies explicitly documenting what happens to insects in a Faraday cage environment. Most available research focuses on broader aspects of electromagnetic field (EMF) exposure or isolation and their effects on different organisms, including mammals, birds, and plants Bandara and Carpenter (2018), Cucurachi et al. (2013). Shielding methods and products against man-made electromagnetic fields have been described in great details elsewhere Panagopoulos and Chrousos (2019). While direct scientific studies on the effects of placing insects in a Faraday cage without exposure to the Schumann resonance are limited, existing research on EMF interactions with insects and other organisms indicates that such isolation could potentially impact their behavior, namely by inhibiting the reproduction abilities of the queen.

Natural and man-made EMFs across various frequencies and intensities have been shown to affect all studied animal and plant species, often with significant implications for wildlife health and survival. Many organisms rely on natural geomagnetic information for vital activities, but their sensitive magnetoreception makes them highly vulnerable to anthropogenic EMFs, potentially contributing to species decline and extinction. As EMF exposures escalate, recognizing EMF as a novel stressor is crucial. Further research is needed to explore factors like electromagnetic radiation affecting honeybee (and other insect and animal) physiology. The combined effect of multiple stressors, interacting across space and time, likely plays a central role in the global decline of honeybee health. Honeybees are increasingly exposed to body-resonant artificial, low-frequency EMFs, such as those from 3G, 4G and 5G telecommunication antennas, which disrupt their magnetic navigation and cause magnetoreception disorders. This may lead to disorientation, reduced forager return rates, and colony collapse disorder. EMF exposure may also affect their physiology and behavior, impairing learning, flight, foraging, feeding, and pollination efficiency. As a result, honeybees may avoid areas with high EMF, further jeopardizing pollination services.

Understanding EMF effects on wildlife and especially on honeybees, involves assessing cumulative impacts, species' compensatory mechanisms, and whether the continual adaptation to a new homeostasis will deteriorate to the point of no return (irreversible collapse).

APPENDIX A

The original report from the Swiss Federal Institute of Technology dealing with the measurements of the attenuation factor of the Faraday- shielded hive can be obtained from the author, upon request.

AUTHOR CONTRIBUTIONS

The first author is Dr. in Biology, teacher, independent researcher, apiary adviser in the Canton de Vaud (Switzerland), was president (from 2010 until mid-2024) of the not-for-profit association Alerte Romande aux Rayonnements

Artificiels (A.R.R.A., formerly A.R.A; www.alerte.ch), and is a member of the scientific advisory board of the not-for-profit association FreeTheBees (www.freethebees.ch). The second author is an Associate Professor, retired from the Karolinska Institute (in Nov 2017, still active), Department of Neuroscience, head of The Experimental Dermatology Unit, Stockholm, Sweden, and Adjunct Professor, previously at the Royal Institute of Technology, Stockholm, Sweden.

CONFLICT OF INTERESTS

None.

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REFERENCES

Bandara, P., & Carpenter, D. O. (2018). Planetary Electromagnetic Pollution: It is Time to Assess its Impact. The Lancet Planetary Health, 2 (12), e512-e514. https://doi.org/10.1016/S2542-5196(18)30221-3

Brown, M. J., Dicks, L. V., Paxton, R. J., Baldock, K. C., Barron, A. B., Chauzat, M. P., ... Stout, J. C. (2016). A Horizon Scan of Future Threats and Opportunities for Pollinators and Pollination. PeerJ, 4, e2249. https://doi.org/10.7717/peerj.2249

Celozzi, S., Araneo, R., Burghignoli, P., & Lovat, G. (2023). Electromagnetic Shielding: Theory and Applications. Wiley.

Charrière, J. D., Imdorf, A., Kuhn, R., & Liebefeld-Posieux, A. (2004). Tolérance Pour Les Abeilles De Différents Traitements Hivernaux Contre Varroa.

Cucurachi, S., Tamis, W. L., Vijver, M. G., Peijnenburg, W. J., Bolte, J. F., & de Snoo, G. R. (2013). A Review of the Ecological Effects of Radiofrequency Electromagnetic Fields (RF-EMF). Environment International, 51, 116-140. https://doi.org/10.1016/j.envint.2012.10.009

Decourtye, A., Alaux, C., Le Conte, Y., & Henry, M. (2019). Toward the Protection of Bees and Pollination Under Global Change: Present and Future Perspectives in a Challenging Applied Science. Current Opinion in Insect Science, 35, 123-131. https://doi.org/10.1016/j.cois.2019.07.008

Faraday, M. (1832). Experimental Researches in Electricity - Volume 1. Read Books Limited.

Favre, D. (2011). Mobile Phone-Induced Honeybee Worker Piping. Apidologie, 42 (3), 270-279. https://doi.org/10.1007/s13592-011-0016-x

Favre, D. (2017). Disturbing Honeybees' Behavior with Electromagnetic Waves: A Methodology. Journal of Behavior, 2 (2), Article 1010.

Favre, D., & Johansson, O. (2020). Does Enhanced Electromagnetic Radiation Disturb Honeybees' Behaviour? Observations During New Year's Eve 2019. International Journal Of Research, 8, 7-14. https://doi.org/10.29121/granthaalayah.v8.i11.2020.2151

Febinger, H. Y., George, A., Priestley, J., Toth, L. A., & Opp, M. R. (2014). Effects of Housing Condition and Cage Change on Characteristics of Sleep in Mice. Journal of the American Association for Laboratory Animal Science, 53 (1), 29-37.

Fleischmann, P. N., Grob, R., & Rössler, W. (2020). Magnetoreception in Hymenoptera: Importance for Navigation. Animal Cognition, 23 (6), 1051-1061. https://doi.org/10.1007/s10071-020-01431-x

Genersch, E. (2010). Honey Bee Pathology: Current Threats to Honey Bees and Beekeeping. Applied Microbiology and Biotechnology, 87 (1), 87-97. https://doi.org/10.1007/s00253-010-2573-8

Halabi, N., Achkar, R., & Haidar, G. A. (2013). The Effect of Cell Phone Radiations on the Life Cycle of Honeybees. Eurocon 2013, 529-536. https://doi.org/10.1109/EUROCON.2013.6625032

Hore, P. J., & Mouritsen, H. (2016). The Radical-Pair Mechanism of Magnetoreception. Annual Review of Biophysics, 45, 299-344. https://doi.org/10.1146/annurev-biophys-032116-094545

Hsu, C. Y., Ko, F. Y., Li, C. W., Fann, K., & Lue, J. T. (2007). Magnetoreception System in Honeybees (Apis mellifera). PLOS ONE, 2 (4), e395. https://doi.org/10.1371/journal.pone.0000395

International Commission on Non-Ionizing Radiation Protection (ICNIRP). (2020). Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz). Health Physics, 118 (5), 483-524. https://doi.org/10.1097/hp.0000000000001210

Kirschvink, J. L. (1981). The Horizontal Magnetic Dance of the Honeybee is Compatible with a Single-Domain Ferromagnetic Magnetoreceptor. Biosystems, 14 (2), 193-203. https://doi.org/10.1016/0303-2647(81)90068-x

Lambinet, V., Hayden, M. E., Reid, C., & Gries, G. (2017). Honey Bees Possess a Polarity-Sensitive Magnetoreceptor. Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology, 203 (12), 1029-1036. https://doi.org/10.1007/s00359-017-1214-4

Lambinet, V., Hayden, M. E., Reigl, K., Gomis, S., & Gries, G. (2017). Linking Magnetite in the Abdomen of Honey Bees to a Magnetoreceptive Function. Proceedings of the Royal Society B: Biological Sciences, 284 (1851). https://doi.org/10.1098/rspb.2016.2873

Levitt, B. B., Lai, H. C., & Manville, A. M. (2022). Effects of Non-Ionizing Electromagnetic Fields on Flora and Fauna, Part 2 impacts: How Species Interact with Natural and Man-Made EMF. Reviews on Environmental Health, 37 (3), 327-406. https://doi.org/10.1515/reveh-2021-0050

Lindauer, M., & Martin, H. (1968). Die Schwereorientierung Der Bienen Unter Dem Einfluß Des Erdmagnetfeldes. Zeitschrift Für Vergleichende Physiologie, 60 (3), 219-243. https://doi.org/10.1007/BF00298600

Migdał, P., Berbeć, E., Bieńkowski, P., Plotnik, M., Murawska, A., & Latarowski, K. (2022). Exposure to Magnetic Fields Changes the Behavioral Pattern in Honeybees (Apis mellifera L.) Under Laboratory Conditions. Animals, 12. https://doi.org/10.3390/ani12070855

Molina-Montenegro, M., Acuña-Rodríguez, I., Ballesteros, G., Baldelomar, M., Torres-Díaz, C., Broitman, B., & Vázquez, D. (2023). Electromagnetic Fields Disrupt the Pollination Service by Honeybees. Science Advances, 9. https://doi.org/10.1126/sciadv.adh1455

Morrison, J. (2014). Electronics' Noise Disorients Migratory Birds. Nature. https://doi.org/10.1038/nature.2014.15176

Morrison, R. (2016). Grounding and Shielding: Circuits and Interference. Wiley.

Nickolaenko, A., & Hayakawa, M. (2014). Schumann Resonance for tyros: Essentials of Global Electromagnetic Resonance in the Earth–Ionosphere Cavity. Springer Japan. https://doi.org/10.1007/978-4-431-54358-9_1

Ohmura, N., Ogino, S., & Okano, Y. (2014). Optimized Shielding Pattern of RF Faraday Cage. 2014 International Symposium on Electromagnetic Compatibility, Tokyo, 765-768.

Panagopoulos, D. J. (2013). Electromagnetic Interaction Between Environmental Fields and Living Systems Determines Health and Well-Being. In Electromagnetic Fields: Principles, Engineering Applications and Biophysical Effects (1st ed., pp. 87-130). Nova Science Publishers.

Panagopoulos, D. J., & Chrousos, G. P. (2019). Shielding Methods and Products Against Man-Made Electromagnetic Fields: Protection Versus Risk. Science of the Total Environment, 667, 255-262. https://doi.org/10.1016/j.scitotenv.2019.02.344

Patsnap, E. B. (2024). Schumann Resonance Generator: Harnessing Earth's Frequency. Patsnap Eureka.

Ramo, S., Whinnery, J. R., & Van Duzer, T. (1994). Fields and Waves in Communication Electronics. Wiley.

Rouleau, N., & Dotta, B. T. (2014). Electromagnetic Fields as Structure-Function Zeitgebers in Biological Systems: Environmental Orchestrations of Morphogenesis and Consciousness. Frontiers in Integrative Neuroscience, 8, 84. https://doi.org/10.3389/fnint.2014.00084

Schumann, W. O. (1952). Über Die Strahlungslosen Eigenschwingungen Einer Leitenden Kugel, Die Von Einer Luftschicht Und Einer Ionosphärenhülle Umgeben Ist. Zeitschrift Für Naturforschung A, 7 (2), 149-154. https://doi.org/10.1515/zna-1952-0202

Sentman, D. D. (2017). Schumann resonances. In Handbook of Atmospheric Electrodynamics, Volume I (Pp. 267-295). Crc Press.

Shaw, J. A., Boyd, A., House, M., Cowin, G., & Baer, B. (2018). Multi-Modal Imaging and Analysis in the Search for Iron-Based Magnetoreceptors in the Honeybee Apis Mellifera. Royal Society Open Science, 5 (9), 181163. https://doi.org/10.1098/rsos.181163

Vanbergen, A. J., Potts, S. G., Vian, A., Malkemper, E. P., Young, J., & Tscheulin, T. (2019). Risk to Pollinators from Anthropogenic Electromagnetic Radiation (EMR): Evidence and knowledge gaps. Science of the Total Environment, 695, 133833. https://doi.org/10.1016/j.scitotenv.2019.133833

Vanengelsdorp, D., Evans, J. D., Saegerman, C., Mullin, C., Haubruge, E., Nguyen, B. K., ... Pettis, J. S. (2009). Colony Collapse Disorder: A Descriptive Study. PLOS ONE, 4 (8), e6481. https://doi.org/10.1371/journal.pone.0006481

Válková, T., & Vácha, M. (2012). How do Honeybees use their Magnetic Compass? Can they see the North? Bulletin of Entomological Research, 102 (4), 461-467. https://doi.org/10.1017/S0007485311000824

Watson, K., & Stallins, J. A. (2016). Honey Bees and Colony Collapse Disorder: A Pluralistic Reframing. Geography Compass, 10 (5), 222-236. https://doi.org/10.1111/gec3.12266

Wever, R. (1970). The Effects of Electric Fields on Circadian Rhythmicity in Men. Life Sciences and Space Research, 8, 177-187.